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A Longitudinal Study of Mandibular Growth Rotation

Richard Steinberg

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Richard Steinberg D.M.D.

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Department of Orthodontics
University of Connecticut Health Center
Farmington, Connecticut 06032

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<u>Introduction</u> - Treatment of skeletal deviations of the jaw can be facilitated if facial growth can be predicted. "Facial growth is controlled by the inherent genetic make-up and the environmental influences upon an individual. Morphologic characteristics of the craniofacial complex are believed to be polygenic in nature and identification of the specific genes or gene groups which control facial morphology has not yet been accomplished. On the side of environmental influences, investigation of treatment effects has revealed that the facio-skeletal growth pattern can be modified by means of orthopedic and orthodontic forces. It has been established that there's a considerable individual variability in the amount, timing and velocity of facial growth and that sex, facial type and heredity are factors that influence individual variability of growth."[1]

In a study concerned with predicting the future growth of a bone, the effects of environment must be minimized. It has been demonstrated by several investigators that mandibular morphology is highly heritable.[2,3,4] Sassouni and Dudas showed that the dimensions N-S-Go, N-S-Gn, lower anterior facial height (palatal plane-menton) and total anterior facial height (SOR-Me) were under strong hereditary or weak environmental influence during growth. Thus if one could quantify the hereditary future of the mandible (within statistical probability) it would be immensely valuable in predicting the individual's growth. The specific aspect of mandibular growth the project will deal with is mandibular growth backwards as it remodels. At the same time he found that nasion was not a stable point for superpositioning, thus the techniques of anterior cranial base superpositioning are compromised. Using superpositioning of implants, Bjork was able to study areas of remodeling, paths of tooth eruption and growth changes. He discovered that little if any, growth occurs at the tip of the chin; and that growth of the condylar cartilage occurs vertically or horizontally along with concurrent changes in direction of mandibular growth and changes in the mandibular morphology.[6] In addition, he found that the lower border of a developing molar germ is fairly stationary until the roots begin to form. To improve the accuracy of superpositioning techniques with longitudinal headfilms, Bjork suggests using natural reference structures. He compares the growth rotation of the mandible with cranial base by measuring the angular change in the superposed nasion-sella line.[7] This technique utilizes the tip of the chin, inner cortical structure of the inferior border of the symphysis, trabecular structures related to the mandibular canal and the lower contour of the molar germ from mineralization until the beginning of root formation. Bjork, using a mixed longitudinal study of approximately 100 Swedish children of each sex, constructed a schematic account of three types of forward mandibular rotations (about the condyles, incisal edges and center of the premolars, Type I, II, III respectively) and two types of backward rotation (about the center of the condyles and last occluding molar, Type I and II respectively). In addition, he summarized a structural technique of predicting mandibular rotation based upon the inclination of the condyle, curvature of the mandibular canal, shape of backwards as it remodels. At the same time he found that nasion was not a stable point for superpositioning, thus the techniques of anterior cranial base superpositioning are compromised. Using superpositioning of implants, Bjork was able to study areas of remodeling, paths of tooth eruption and growth changes. He discovered that little if any, growth occurs at the tip of the chin; and that growth of the condylar cartilage occurs vertically or horizontally along with concurrent changes in direction of mandibular growth and changes in the mandibular morphology.[6] In addition, he found that the lower border of a developing molar germ is fairly stationary until the roots begin to form. To improve the accuracy of superpositioning techniques with longitudinal headfilms, Bjork suggests using natural reference structures. He compares the growth rotation of the mandible with cranial base by measuring the angular change in the superposed nasion-sella line.[7] This technique utilizes the tip of the chin, inner cortical structure of the inferior border of the symphysis, trabecular structures related to the mandibular canal and the lower contour of the molar germ from mineralization until the beginning of root formation. Bjork, using a mixed longitudinal study of approximately 100 Swedish children of each sex, constructed a schematic account of three types of forward mandibular rotations (about the condyles, incisal edges and center of the premolars, Type I, II, III respectively) and two types of backward rotation (about the center of the condyles and last occluding molar, Type I and II respectively). In addition, he summarized a structural technique of predicting mandibular rotation based upon the inclination of the condyle, curvature of the mandibular canal, shape of lower border of the mandible, inclination of the symphysis, interincisal angle, interpremolar angles and anterior lower face height.[3]

In another implant study of twenty-one subjects, Bjork and Skeiller quantified facial development in relation to mandibular growth rotation.[8] Nineteen subjects demonstrated forward growth rotation with a mean of seven degrees (over the five to six years pubertal growth period.) It was noted that more than half of the forward rotation was marked by remodeling by bony apposition below the symphysis and resorption below the angle of the mandible. In the two cases of backward growth rotation there was remodeling in the opposite direction with slight apposition below the symphysis and marked apposition below the angle of the mandible. The mean decrease in gonial angle over the five to six year growth period was 2.4° by the probable mechanism of bony apposition at the posterior border of the mandible and resorption at the lower border. Marked rotation of the jaws during growth causes compensatory adaptation in tooth eruption. In forward growth rotation patterns the intermaxillary growth space wedges anteriorly and in posterior patterns wedges posteriorly. Mandibular rotation correlated strongly with intensity and direction of condylar growth and with change in gonial angle.

Enlow and Moyers[9] demonstrated how structural variation in development can produce facial balance. For example, with posterior rotation of the mandible the anterior maxillary height increased, the occlusal plane, aligned by alveolar growth and mandibular molars, intruded to increase overbite. Forward rotations produced opposite effects.

Another study of mandibular rotation utilizing implants was done by Odegaard.[10] He analyzed the degree of rotation of the mandible in relation to facial skeleton, age, sex and orthodontic treatment. An interesting finding was that orthodontic treatment led to a decrease in anterior rotation when measured to the S-N line. Possibly, this could be due to eruptive treatment techniques. A significant finding was that when estimating the growth of the mandible, the evaluation must be based on the mandible alone and not its position in space (i.e., degree of rotation was unrelated to degree of prognathism and degree of cranioflexure angle, but was related to mandibular morphology.)

Additional insight into the area was shown in a cephalometric study by Isaacson, J. et al.[11] He states that it is necessary for vertical growth in the anterior face to exactly equal vertical growth in the posterior face to prevent rotation at the mandibular articulation. He studied changes in ramus height, post maxillary and mandibular height and vertical position of the glenoid fossa. An interesting point he makes is that A-P position of the teeth can be expected to affect mandibular rotation. As teeth or skeletal parts are located posteriorly, the MP-SN angle can be expected to increase and vice-versa. Similarly, a loss in anchorage during treatment would decrease the angle. Additionally he indicated that backward rotating mandibles increase facial height and therefore elongate the facial musculature. It is suggested that this increases the tension and can constrict the maxillary arch. His data shows higher incidence of buccal crossbite in backward rotating patterns. Similarly, increased lower facial height results in increased level of mentalis activity to raise the lower lip for a seal which will affect lower incisor position. One can construct typical patterns and apply these relationships clinically. For example, if a patient presents with an anterior open bite and a low MP-SN angle one would think the etiology was environmental and the prognosis would be good once the habit was corrected. Isaacson, et al, ranked descriptive parameters and discovered that vertical height of the maxillary molar was significant in predicting MP-SN angle. Therefore, mandibles that rotate backward might indicate intrusive molar mechanics and vice-versa. Similarly, changes in vertical position of the glenoid fossa would produce the same effect as vertical changes in ramus height.

A study of mandibular growth relative to cranial base was done by Knott.[12] She investigated the changes in size and position Pg-Postgonion relative to cranial base (Frontal sinus point and Pituitary point). Although she quantified the changes to demonstrate growth means, she superimposed several quadrilaterals on her cranial base segment at age six and early adulthood to show individual variation in size and angles. Her examples showed horizontal, vertical and combinations of both patterns in what Bjork would define as forward and backward rotation patterns. Similarly, if her points Pg and Postgonion were used to superpose, the angle between her cranial base lines would show type and degree of rotations.

There are several difficulties in longitudinal cephalometric studies. Johnston[13] suggested that accuracy may be limited by errors in the cephalometric method itself.

According to Baumrind et al[14] tracing comparisons have three error sources: 1. "errors of projective displacement" 2. "landmark identification" 3. "inaccuracy in superpositioning". They concluded that while superpositioning errors may be large when comparing two headfilms, they should not be of consequence in a large sample of headplates.

Hirshfield and Moyers[15] added two additional limitations: 1. assuming that the growth coefficients remain constant over the study and 2. the difficulty of making a prediction in a different population group.

Materials and Methods

This study utilized headfilms from the Denver Growth Center taken at approximately one year intervals for the purpose of investigating the relationship between eight structural parameters and mandibular rotation and A-Pg(OP) changes over two years.

The sample consisted of 35 males and 31 females who were x-rayed annually. Each sex was divided into six chronological age categories with each film placed into the nearest whole year group between ages 10.0 and 15.0. As there were insufficient wristfilms available to determine skeletal age, chronological age was used. Several films are missing in all categories.

Eight cephalometric measurements were made on each film: 1. Gonial angle 2. Symphyseal angle 3. A-Pg(OP) 4. UR6 (pFH) 5. ANS-Me (pFH) 6. Ar-Go (pFH) 7. Ar-Pg 8. N-S to OP angle (Fig.1). Symphyseal angle is defined as the inside angle between the N-S line and a line that approximates the best straight line fit of the symphysis of the chin in the area between point B and Pogonion. Parentheses

Parentheses indicated that the points are to be measured along that horizontal plane. (pFH) is measured on a perpendicular to frankfort horizontal. The frankfort horizontal used is a line drawn seven degrees below the N-S line. The occlusal plane is the line which connects the mesio-buccal cusp tip of the upper right first molar with a point that bisects the subject's overbite. The ramal plane connects articulare with the posteriormost point in the lower one third of the ramus. The mandibular plane connects menton with the inferiormost point of the posterior one third of the mandibular body. A constructed gonial angle is measured between ramal plane and mandibular plane. The vertex of this angle is the gonion. UR6 refers to the mesiobuccal cusp of the maxillary right first molar.

The tracing for age ten was superimposed on age eleven and growth rotation was measured. The superpositioning technique utilized the anterior border of the chin and the inner cortical structure of the inferior border of the symphysis (Fig. 2). Growth rotation is defined as the angle between the N-S lines of the first and second films. A positive, or forward, rotation was used if the lines crossed at a point anterior to the older age's headfilms sella point and a negative rotation if they crossed posteriorly. Similarly, the film at age eleven was superimposed on age twelve, twelve on thirteen, thirteen on fourteen, fourteen on fifteen. If a film was missing, the next oldest film was used and the growth rotation was divided by the number of intervening years. This maintained the sample size of each measurement without having a large effect on accuracy. At most, four of the thirty-five male subjects and five of the thirty-one females were missing.

All headfilms were digitized using a tablet digitizer (Summagraphics, Fairfield, Connecticut). All measurements were made using computer programs in BASIC on a Computer Automation (Irvine, California) alpha-16 mini-computer at the Department of Orthodontics, University of Connecticut School of Dental Medicine. Correlations were run on an 1106 Univac and an SPSS computer program. To test tracing reproducibility two tracings were repeated five times on the headfilms of five subjects in each of two age groups. A one way analysis of variance was performed on the differences in variable measurements. There were no significant differences for any measurements.

Correlations as well as descriptive statistics of the samples were studied for allvariables. Multiple regression analysis was performed comparing two year's growth rotation and two year changes in A-Pg(OP) with the eight craniofacial dimensions at ages ten, eleven, twelve and thirteen. The sexes were analyzed separately.

The variable symphyseal angle accounted for more variation than other variables in growth rotation. Regression analysis was done versus symphyseal angle alone.

Results

Tables A through F show means, standard deviations and distribution of variables in each group.

The following variables were significantly correlated ($p < .05$) at all ages versus two year's growth. All listed coefficients were positive.

Males

Variables	Age 10 sig	Age 10 coef	Age 11 sig	Age 11 coef	Age 12 sig	Age 12 coef	Age 13 sig	Age 13 coef
Gonial Angle to Ar-Pg	.002	.497	.003	.474	.001	.563	.001	.530
A-Pg(OP) to NS-OP Angle	.001	.577	.001	.538	.022	.371	.002	.489
UR6(pFH) to Ar-Pg	.001	.568	.005	.451	.001	.530	.003	.468
UR6(pFH) to ANS-Me(pFH)	.001	.564	.001	.648	.001	.619	.001	.600
ANS-Me(pFH) to Ar-Pg	.001	.661	.002	.484	.001	.696	.001	.598
Ar-Go(pFH) to Ar-Pg	.001	.564	.002	.487	.002	.493	.001	.550

Females

Variables	Age 10 sig	Age 10 coef	Age 11 sig	Age 11 coef	Age 12 sig	Age 12 coef	Age 13 sig	Age 13 coef
A-Pg(OP) to NS-OP Angle	.020	.389	.002	.507	.008	.453	.046	.344
UR6(pFH) to ANS-Me(pFH)	.001	.626	.001	.616	.001	.743	.001	.643
UR6(pFH) to Ar-Go(pFH)	.031	.357	.001	.553	.022	.382	.001	.574
UR6(pFH) to Ar-Pg	.001	.716	.001	.775	.001	.720	.001	.829
Ar-Go(pFH) to Ar-Pg	.001	.681	.001	.688	.001	.575	.002	.555

Multiple regression analysis showed the following significant relationships (- = not significant at .05 level, * = significant at the .05 level, ** = significant at .01 level).

Males two year growth rotation age 10-12 vs. one variable at age 10:

Gonial Angle $(r^2 = .163)$*

Males two year growth rotation age 13-15 vs. four variables at age 13:

	r^2	Δr^2
Symphyseal Angle	.176*	.176
ANS-Me(pFH)	.335**	.159
A-Pg(OP)	.361*	.026
Ar-Go(pFH)	.365*	.004

Females two year A-Pg(OP) changes age 10-12 vs. five variables at age 10:

	r^2	Δr^2
UR6(pFH)	.251**	.251
Ar-Go(pFH)	.310*	.059
A-Pg(OP)	.359*	.049
Symphyseal Angle	.387*	.028
Ar-Pg	.414*	.027

Females two year growth rotation age 13-15 vs. seven variables at age 13:

	r^2	Δr^2
Gonial Angle	.224-	.224
NS-OP	.606**	.382
Symphyseal Angle	.716**	.110
UR6(pFH)	.795**	.079
A-Pg(OP)	.807**	.011
ANS-Me(pFH)	.824*	.017
Ar-Go(pFH)	.831*	.008

Females two year A-Pg(OP) changes age 13-15 vs. two variables at age 13:

	r^2	Δr^2
A-Pg(OP)	.417**	.417
Gonial Angle	.445*	.029

The values for Δr^2 demonstrate the strength of the additional variable as a predictor. Thus in the above analysis, A-Pg(OP) (Δr^2 = .417) was almost 14 times as strong a predictor as Gonial Angle (r^2 = .029).

When it was seen that Symphyseal Angle accounted for more variation in growth rotation than the other variables, this variable was analyzed alone versus the two year growth rotation and the two year A-Pg(OP) changes. It was found to be a significant predictor at the .05 level in the following samples:

Males two year's growth rotation age 12-14 vs. Symphyseal Angle age 12:

Symphyseal Angle r^2 = .156

Males two year's growth rotation age 13-15 vs. Symphyseal Angle age 13:

Symphyseal Angle r^2 = .177

Discussion

The purpose of this study is to describe the growth changes in the mandible that can be expected during a typical orthodontic treatment span of two years. Growth rotation describes mandibular movement in relation to skeletal cranial base. A-Pg(OP) changes describe the effect of mandibular growth relative to the occlusal plane. This dimension tells the orthodontist how skeletal growth changes the effective tooth bearing area on which he must align the dentition. Thus a positive A-Pg(OP) change means there is an increase in the area available to place the dentition and vice versa. An attempt was made to quantify the relationship of eight craniofacial dimensions to growth rotation and A-Pg(OP) to see if growth prediction was a possibility. However, only in females age 13-15 did seven of the variables suggest the pattern of growth; accounting for 83.1% of the variance. Although other patterns were discernable, they accounted for only 15 to 45% of the variance and are not useful clinically. Either these variables cannot predict future growth, or because of the complicated interactions involved in growth and the extent of individual variation individualized growth prediction is precluded. One could explain the pattern in 13 year females to be due to the small amount of growth remaining ($\bar{x}$ = 1.97°) at that age.

This lack of predictability is undoubtedly due for the most part, to the great variability of the time of onset, amplitude, and duration of the growth spurt. Thus, attempts to predict growth more accurately than that obtainable by applying expected values to present status, are unlikely to be improved upon by regression methods.

However, in males symphyseal angle was significant in two age categories: growth rotation 12-14 (r^2 = 15.6%) and growth rotation 13-15 (r^2 = 17.7%). Although the variance accounted for is low, the relationships occur at peak growth velocity. As Bjork suggests the contour of the symphysis of the mandible is related to the pattern of future growth.

R was plotted (Fig. 3A) against age to show the relationship between the significance of symphyseal angle and peak growth velocities.

For males, symphyseal angle is a better predictor at large growth velocities (12-14, 13-15). The female sample did not show this relationship although the highest correlation occurred at 12-14 years.

The plot of R (Fig. 3B) vs. age for two year change in A-Pg(OP) shows no pattern, however, for males the highest correlations occurred during periods of small changes and for females highest correlations occurred during periods of greatest change.

The mean two year growth rotations (Fig. 3C) followed normal growth patterns, i.e., males peaked at 13-15 and females at 11-13. However, A-Pg(OP) peak changes (Fig. 3D) occurred at 11-13 in males and 12-14, 13-15 in females. This may be due to rapid changes in A-Pg(OP) when there are small changes in the cant of occlusal plane while large amounts of mandibular growth would only moderately affect A-Pg(OP). The dimension NS-OP shows a flattening during peak growth velocities in males and females (Fig. 4). This would counteract the effect of mandibular growth on A-Pg(OP). In addition, for both sexes at all ages A-Pg(OP) and NS-OP angle were significantly correlated.

The flattening of occlusal plane with growth explains how anterior-posterior dental relationships remain the same or worsen with growth even though the skeletal relationships are improving. This is caused by a decrease in the dimension A-Pg(OP) and thus the effective denture bearing area. Possibly one objective of orthodontic treatment should be to maintain the cant of occlusal plane, with which the patient presents, and to prevent the natural tendency for it to flatten.

Descriptive Data

From the means and standard deviations for two years changes in growth rotations and A-Pg(OP) (Fig. 3), it can be seen that over a two year period the average individual can expect a forward rotation of the mandible of approximately two degrees. During peak velocities this average approaches slightly more than three degrees in both sexes. The five year mean changes in males amounted to $+6.42^{\circ}$ and in females $+5.99^{\circ}$. These numbers are very similar to the figure of $+7^{\circ}$ that Bjork and Skeiller[9] reported in their study of five to six years growth changes with the use of implants. The data on one year growth rotation showed the most common range to be $+1.0^{\circ}$ or less in males in each of the five one-year intervals, and $+1.0^{\circ}$ or less in three of the five female intervals (11-12 and 13-14 the most common range was $1.01 - 2.0^{\circ}$). It is stressed that although the means demonstrated a forward rotational pattern, individuals showed frequent changes in rotational direction over one year changes. A person with a forward rotational pattern could show a backward pattern at times along the growth curve. Only two females of the 66 male and female subjects displayed a negative mean rotation over the five year period.

The data on A-Pg(OP) changes demonstrated very small changes over a two year span for either sex. Without treatment very little A-P dental changes can be expected. The five year mean change for males was -.44 and for females +.41. Thus, over a five year span with no intervening treatment, the average female will only show about ½ mm of anterior-posterior improvement with growth, and the average male ½ mm worsening. However, there is a large amount of individual variation. The data on one year changes in A-Pg(OP) demonstrates a consistent most common range between -.99 and +1.00mm (exception being females 10-11, most common range of -1.00 to -2.49). It is interesting to note that during the pubertal growth spurt the tendency in both sexes is for a negative change in A-Pg(OP) in the one year period. That is, during peak growth velocities with no treatment, the occlusal situation (i.e., the effective denture base) should worsen in the average individual.

Summary

This study used lateral headfilms of 31 female and 35 male children from the Denver Growth Study taken between 10 and 15 years old. Growth was measured by superpositions of successive headfilms.

An attempt was made to develop an individualized two year prediction of mandibular growth rotation and A-Pg(OP) changes by performing multiple regression analysis of these two measurements versus eight craniofacial variables that would describe mandibular morphology. These variables were gonial angle, symphyseal angle, A-Pg(OP), UR6(pFH), ANS-Me(pFH), Ar-Go(pFH), Ar-Pg and NS to OP angle.

Although several patterns emerged, none were clinically useful. The strongest relationship was for females' two year growth rotation between age 13-15. Seven of the variables (all except Ar-Pg) accounted for 83.1% of the variance. However, there was a very small amount of growth ($\bar{x} = 1.97^{o}$) during this period.

The significance of symphyseal angle as a predictor of growth rotation improves during peak growth velocities. No such pattern emerged for A-Pg(OP).

The mean two year growth rotations peaked at normal pubertal growth spurts in both males and females. The mean two year A-Pg(OP) changes peaked at periods of lower growth velocities.

The five year mean changes of growth rotation was $+6.42^{o}$ in males and $+5.99^{o}$ in females. This was similar to the value of $+7^{o}$ that Bjork and Skeiller reported[8] over a five to six year period in a study that utilized implants.

The five year mean changes in A-Pg(OP) were small, -.44mm for males and +.41mm for females.

Clinically, solid prediction is difficult, due to the large variability of time of onset, amplitude and duration of the growth spurt. Future work in this area might concern itself with predicting the baseline growth patterns of specific bones and quantifying growth changes during pubertal growth spurts. By analyzing the baseline growth with pubertal increases one may come closer to individualizing growth predictions.

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Cephalometric Measurements

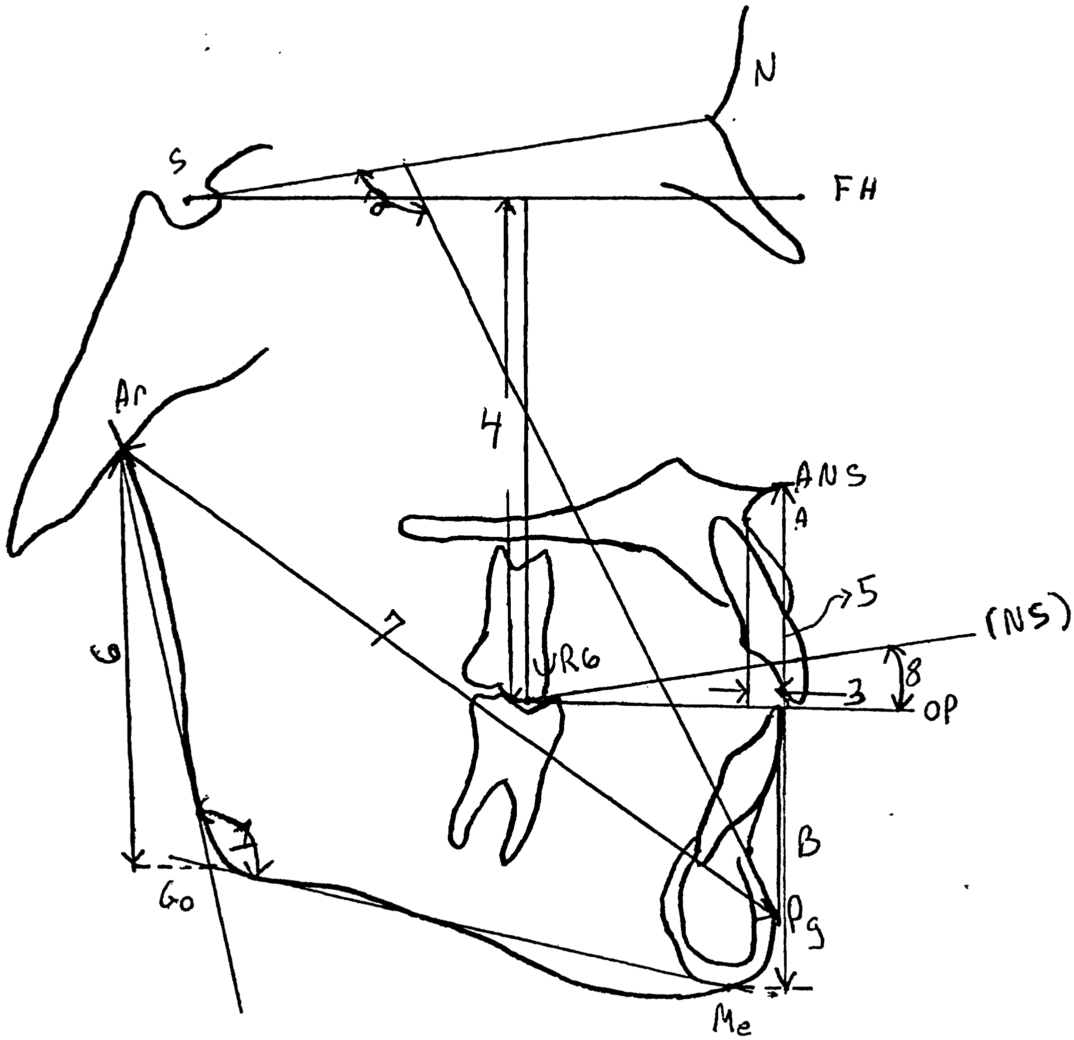


Figure I:

1. Gonial Angle (degrees) 2. Symphyseal Angle (degrees)
3. A-Pg(OP) (mm) 4. UR6(pFH) (mm) 5. ANS-Me(pFH) (mm)
6. Ar-Go(pFH) (mm) 7. Ar-Pg (mm) 8. N-S to OP Angle (degrees)

Growth Rotation

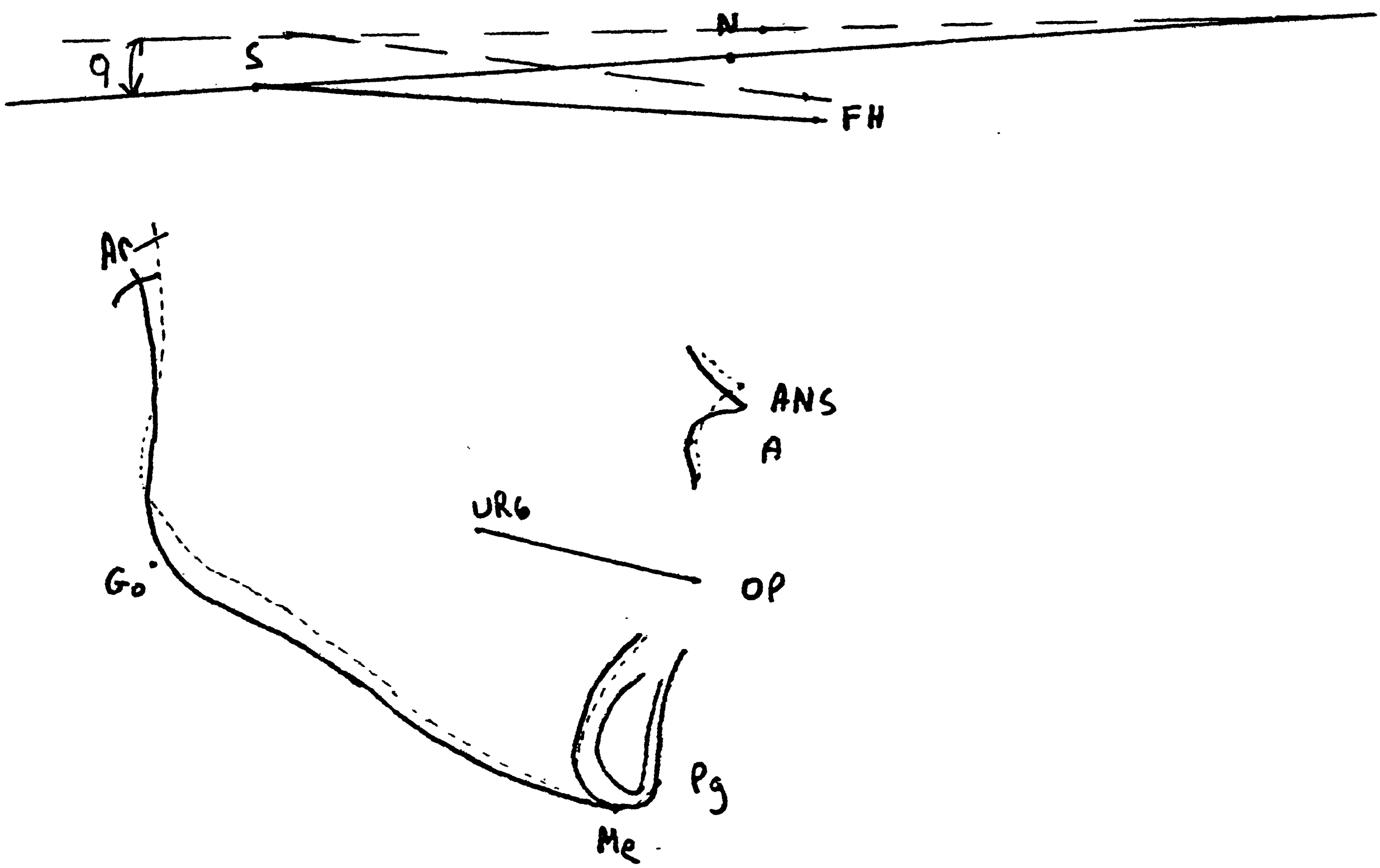
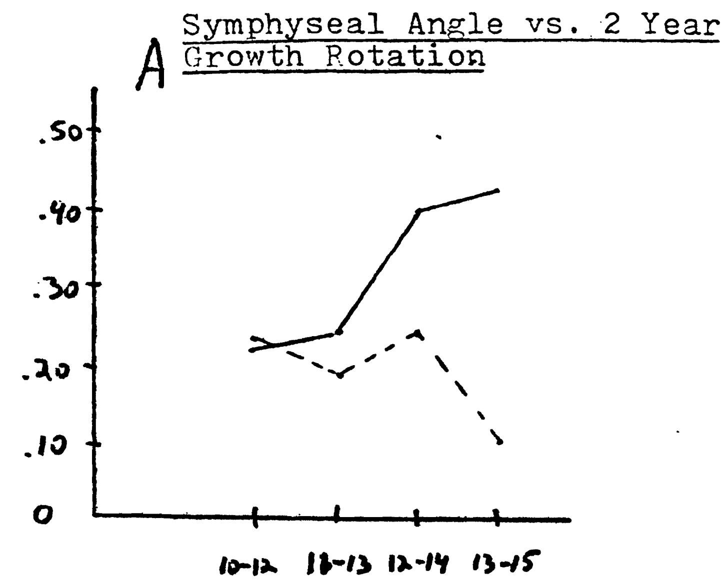
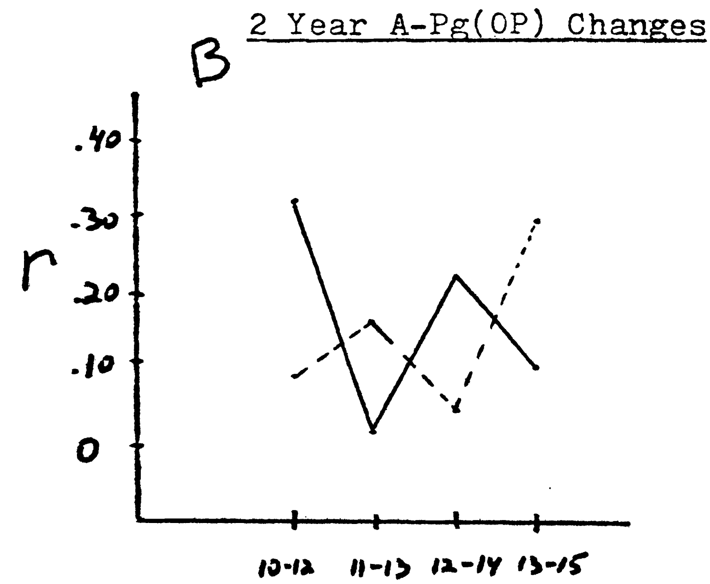


Figure 2: Solid line represents film 1, dotted line represents film 2. 9 is the growth rotation measured in degrees.





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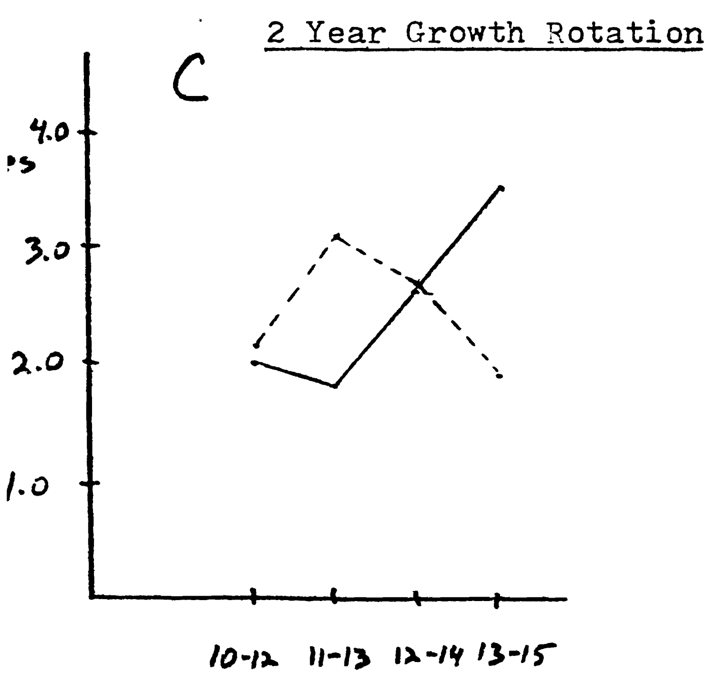

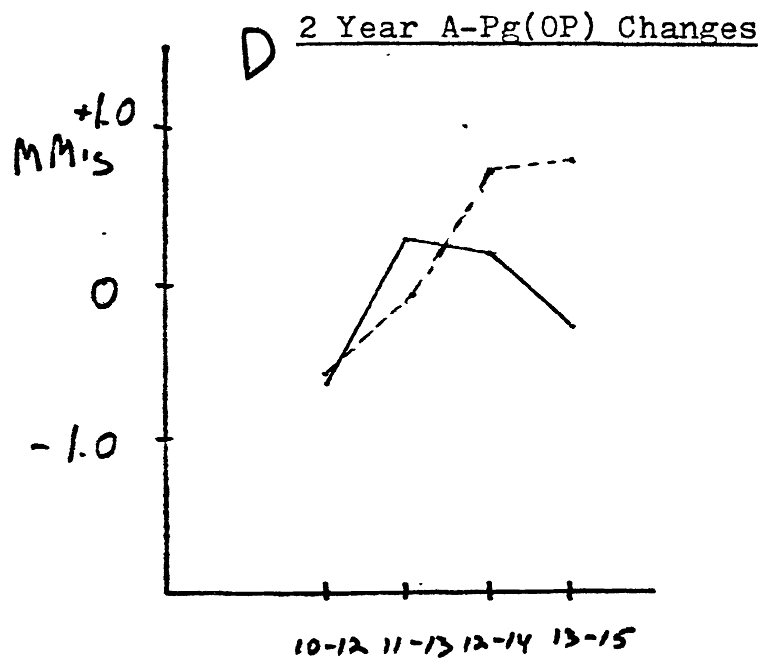

Figure 3: —— = Males ----- = Females

Mean Values of N-S to Occlusal Plane Angle

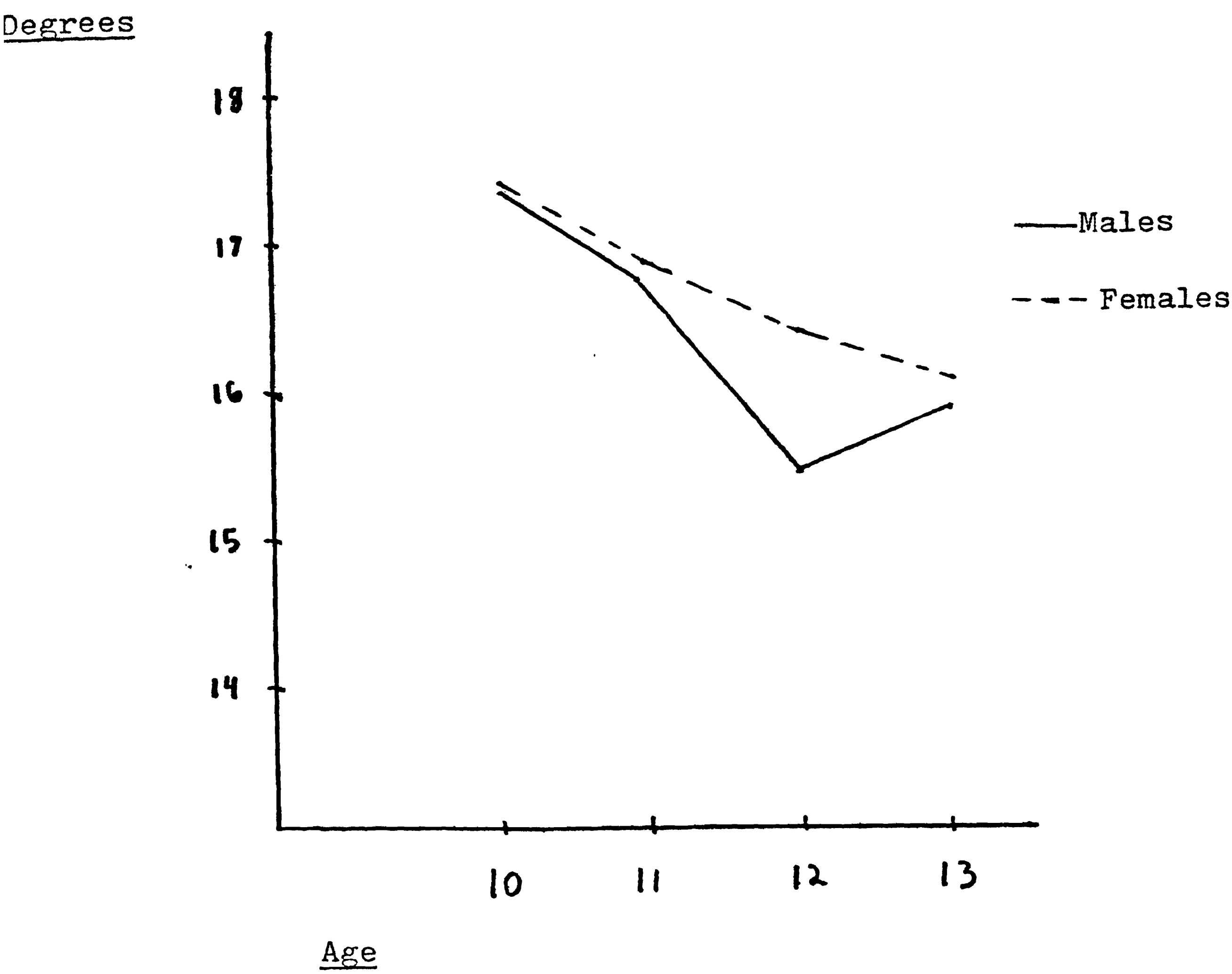

Figure 4

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Table A

Males

Age		10	11	12	13
Gonial Angle	Cases	32	32	31	33
	Mean	123.35	122.84	121.89	122.33
	Standard Deviation	6.81	6.04	6.27	6.50
Symphyseal Angle	Cases	32	32	31	33
	Mean	86.61	83.89	82.39	82.34
	Standard Deviation	4.48	4.10	4.39	5.52
A-Pg(OP)	Cases	32	32	31	33
	Mean	2.28	2.01	1.17	2.13
	Standard Deviation	3.48	3.70	3.20	3.82
UR6(pFH)	Cases	32	32	31	33
	Mean	59.21	60.73	62.36	63.95
	Standard Deviation	2.15	2.55	2.49	2.74
ANS-Me(pFH)	Cases	32	32	31	33
	Mean	57.58	58.73	59.46	60.77
	Standard Deviation	3.54	3.39	3.30	4.02
Ar-Go(pFH)	Cases	32	32	31	33
	Mean	41.73	42.68	43.56	44.83
	Standard Deviation	3.39	3.69	3.02	3.99
Ar-Pg	Cases	32	32	31	33
	Mean	96.55	98.52	100.42	102.76
	Standard Deviation	3.99	3.78	4.27	4.56
NS-OP Angle	Cases	32	32	31	33
	Mean	17.35	16.70	15.46	15.88
	Standard Deviation	3.40	3.46	3.28	3.48
2 Year Growth	Cases	31	33	33	28
	Mean	2.05	1.88	2.69	3.46
	Standard Deviation	1.87	1.87	1.53	2.04
2 Year A-Pg(OP) Change	Cases	31	33	33	28
	Mean	-.64	.28	.19	-.26
	Standard Deviation	1.51	2.18	1.65	2.41

Females

Age		10	11	12	13
Gonial Angle	Cases	28	29	28	26
	Mean	122.49	122.09	122.44	120.97
	Standard Deviation	6.89	6.62	6.33	6.51
Symphyseal Angle	Cases	28	29	28	26
	Mean	82.49	83.16	82.60	82.43
	Standard Deviation	6.28	5.89	6.57	6.29
A-Pg(OP)	Cases	28	29	28	26
	Mean	2.76	2.25	2.18	2.49
	Standard Deviation	2.69	3.39	3.37	3.23
UR6(pFH)	Cases	28	29	28	26
	Mean	56.38	57.87	59.29	61.17
	Standard Deviation	3.16	3.19	3.07	3.06
ANS-Me(pFH)	Cases	28	29	28	26
	Mean	55.22	55.83	57.24	58.18
	Standard Deviation	3.18	3.45	4.01	4.19
Ar-Go(pFH)	Cases	28	29	28	26
	Mean	39.48	40.23	41.12	42.60
	Standard Deviation	2.51	2.65	2.96	3.41
Ar-Pg	Cases	28	29	28	26
	Mean	92.64	94.59	95.99	98.32
	Standard Deviation	3.92	4.57	4.57	4.79
NS-OP Angle	Cases	28	29	28	26
	Mean	17.40	16.84	16.40	16.08
	Standard Deviation	3.82	3.99	3.66	3.31
2 Year Growth	Cases	28	30	27	21
	Mean	2.15	3.09	2.71	1.97
	Standard Deviation	2.46	2.46	1.78	1.85
2 Year A-Pg(OP) Change	Cases	26	30	28	20
	Mean	-.61	-.13	.71	.77
	Standard Deviation	1.91	1.41	1.51	1.69

Table B

Gonial Angle

Males

Degrees	10	11	12	13	14	15
< 116.99	6 18.8%	7 21.9%	4 12.9%	8 24.2%	3 10.7%	9 32.1%
117-121.99	8 25%	8 25%	14 45.2%	10 32.3%	14 50%	10 35.7%
122-126.99	10 31.3%	9 28.1%	7 22.6%	8 24.2%	4 14.3%	4 14.3%
127-131.99	4 12.5%	5 15.6%	4 12.9%	3 9.1%	4 14.3%	2 7.1%
132-136.99	3 9.4%	2 6.3%	2 6.5%	4 12.1%	3 10.7%	2 2.1%
> 137.00	1 3.1%	1 3.1%	0	0	0	1 3.6%
N=	32	32	31	33	28	28

Gonial Angle

Females

Degrees	10	11	12	13	14	15
< 116.99	5 17.9%	5 24.1%	7 14.3%	4 15.6%	4 19.2%	8 36.4%
117-121.99	10 35.7%	10 34.5%	13 46.4%	14 53.8%	11 42.3%	5 22.7%
122-126.99	5 17.9%	5 17.2%	4 14.3%	4 15.4%	4 15.4%	5 22.7%
127-131.99	7 25%	5 17.2%	5 17.9%	1 3.8%	5 19.2%	4 18.2%
132-136.99	0	1 3.4%	1 3.6%	2 7.7%	1 3.8%	0
> 137.00	1 3.6%	1 3.4%	1 3.6%	1 3.8%	0	0
N=	28	29	28	26	26	22

Symphyseal Angle

Males

Degrees	10	11	12	13	14	15
< 70.99	0	1 3.1%	0	2 6.1%	3 10.7%	1 3.6%
71-74.99	2 6.3%	0	2 6.5%	2 6.1%	2 7.1%	5 17.9%
75-79.99	3 9.4%	4 12.5%	7 22.6%	7 21.2%	3 10.7%	6 21.4%
80-84.99	12 37.5%	13 40.6%	10 32.3%	7 21.2%	12 42.9%	10 35.7%
85-88.99	12 37.5%	14 43.8%	12 38.7%	13 39.4%	6 21.4%	5 17.9%
> 89	3 9.4%	0	0	2 6.1%	2 7.1%	1 3.6%
N=	32	32	31	33	28	28

Symphyseal Angle

Females

Degrees	10	11	12	13	14	15
< 70.99	1 3.6%	2 6.9%	2 7.1%	1 3.8%	1 3.8%	2 9.1%
71-74.99	2 7.1%	2 6.9%	2 7.1%	2 7.7%	1 3.8%	0
75-79.99	3 10.7%	2 6.9%	3 10.7%	4 15.4%	2 7.7%	4 18.2%
80-84.99	10 35.7%	7 24.1%	10 35.7%	7 26.9%	10 38.5%	7 31.8%
85-89.99	10 35.7%	14 48.3%	6 21.4%	10 38.5%	9 34.6%	8 36.4%
> 89	2 7.1%	2 6.9%	5 17.9%	2 7.7%	3 11.5%	1 4.5%
N=	28	29	28	26	26	22

Table C

A-Pg(OP)

Males

mm	10	11	12	13	14	15
<-6.00	0	1 3.1%	1 3.3%	0	1 3.6%	0
-5.99- -1.00	6 19.4%	4 12.5%	6 20%	7 21.2%	6 21.4%	6 22.2%
-.99- +4.99	19 61.3%	22 68.8%	22 73.3%	17 51.5%	16 57.1%	18 66.7%
+5.0-+9.99	4 12.9%	3 9.4%	1 3.3%	9 27.3%	5 17.9%	1 3.7%
+10.0-+14.99	2 6.5%	2 6.3%	0	0	0	2 7.4%
N=	31	32	30	33	28	27

A-Pg(OP)

Females

mm	10	11	12	13	14	15
<-6.00	0	0	0	0	1 3.8%	0
-5.99- -1.00	0	5 17.2%	4 14.3%	0	0	0
-.99- +4.99	2 7.1%	0	0	2 8.0%	1 3.8%	4 18.2%
+5.00- +9.99	20 71.4%	18 62.1%	20 71.4%	17 68.0%	19 73.1%	11 50.0%
+10.0-+14.99	6 21.4%	5 17.2%	3 10.7%	5 20.0%	5 19.2%	6 27.3%
>+15.00	0	1 3.4%	1 3.6%	1 4.0%	0	0
	0	0	0	0	0	1 4.5%
N=	28	29	28	25	26	22

UR6(pFH)

Males

MM	10	11	12	13	14	15
<55.99	2 6.3%	2 6.3%	0	0	0	0
56.0-59.99	19 59.4%	11 34.4%	4 12.9%	3 9.1%	0	0
60.0-63.99	11 34.4%	16 50.0%	19 61.3%	13 39.4%	6 21.8%	1 3.6%
64.0-67.99	0	3 9.4%	8 25.8%	15 45.5%	15 53.6%	10 35.7%
68.0-71.00	0	0	0	2 6.1%	7 25.0%	15 53.6%
>72.00	0	0	0	0	0	2 7.1%
N=	32	32	31	33	28	28

UR6(PFH)

Females

MM	10	11	12	13	14	15
<55.99	13 46.4%	10 34.5%	4 14.3%	0	0	0
56.0-59.99	9 32.1%	12 41.4%	11 39.3%	10 38.5%	5 19.2%	1 4.5%
60.0-63.99	6 21.4%	5 17.2%	11 39.3%	11 42.3%	14 53.8%	10 45.5%
64.0-67.99	0	2 6.9%	2 7.1%	4 15.9%	5 19.2%	7 31.8%
>68.0	0	0	0	1 3.8%	2 7.7%	4 18.2%
N=	28	29	28	26	26	22

Table D

ANS-Me(pFH)
Males

MM	10	11	12	13	14	15
<55.99	12 37.5%	8 25%	7 22.6%	5 15.2%	1 3.6%	0
56-59.99	11 34.4%	9 28.1%	8 25.8%	9 27.3%	8 28.6%	3 10.7%
60-63.99	9 28.1%	13 40.6%	14 45.2%	12 36.4%	9 32.1%	9 32.1%
64-67.99	0	2 6.3%	2 6.5%	6 18.2%	7 25%	11 39.3%
68-71.99	0	0	0	1 3%	2 7.1%	3 10.7%
>72.0	0	0	0	0	1 3.6%	2 7.1%
N=	32	32	31	33	28	28

ANS-Me(pFH)
Females

MM	10	11	12	13	14	15
<55.99	16 57.1%	16 55.2%	12 42.9%	8 32.8%	6 23.1%	4 18.2%
56-59.99	10 35.7%	10 34.5%	9 32.1%	10 38.5%	9 34.6%	5 22.7%
60-63.99	2 7.1%	3 10.3%	5 17.9%	5 19.2%	7 26.9%	10 45.5%
64-67.99	0	0	2 7.1%	3 11.5%	4 15.4%	1 4.5%
>68.0	0	0	0	0	0	2 9.1%
N=	28	29	28	26	26	22

Ar-Go(pFH)
Males

MM	10	11	12	13	14	15
<37.99	6 18.8%	2 6.3%	0	1 3.0%	0	0
38-41.99	11 34.4%	12 37.5%	10 32.3%	9 27.3%	1 3.6%	1 3.6%
42-45.99	13 40.6%	12 37.5%	14 45.2%	11 33.3%	14 50%	8 28.6%
46-49.99	1 3.1%	5 15.6%	7 22.6%	8 24.2%	7 25.0%	10 35.7%
50-53.99	1 3.1%	1 3.1%	0	4 12.1%	5 17.9%	7 29.0%
>54.0	0	0	0	0	1 3.6%	2 7.1%
N=	32	32	31	33	28	28

Ar-Go(pFH)
Females

MM	10	11	12	13	14	15
<37.99	10 35.7%	6 20.7%	4 14.3%	2 7.7%	0	0
38-41.99	13 46.4%	17 58.6%	14 50.0%	10 38.5%	6 23.1%	0
42-45.99	5 17.9%	5 17.2%	8 28.6%	10 38.5%	14 53.8%	12 54.5%
46-49.99	0	1 3.4%	1 3.6%	4 15.4%	4 15.4%	6 27.3%
>50.0	0	0	1 3.6%	0	2 7.7%	4 18.2%
N=	28	29	28	26	26	22

Ar-Pg
Males

MM	10	11	12	13	14	15
<92.99	7 21.9%	2 6.3%	1 3.2%	0	0	0
93-97.99	12 37.5%	11 34.4%	9 29.0%	6 18.2%	0	0
98-102.99	12 37.5%	15 46.9%	13 41.9%	11 33.3%	9 32.1%	4 14.3%
103-107.99	1 3.1%	4 12.5%	7 22.6%	11 33.3%	13 46.4%	13 46.4%
108-112.99	0	0	1 3.2%	5 15.2%	3 10.7%	5 17.9%
>113	0	0	0	0	3 10.7%	6 21.4%
N=	32	32	31	33	28	28

Ar-Pg
Females

MM	10	11	12	13	14	15
<92.99	13 46.4%	14 48.3%	7 25.0%	3 11.5%	0	0
93-97.99	12 42.9%	9 31.0%	12 42.9%	13 50.0%	8 30.8%	4 18.2%
98-102.99	3 10.7%	4 13.8%	7 25.0%	6 23.1%	9 34.6%	9 40.9%
103-107.99	0	2 6.9%	2 7.1%	2 7.7%	6 23.1%	4 18.2%
>108	0	0	0	2 7.7%	3 11.5%	5 22.7%
N=	28	29	28	26	26	22

NS-CP
Males

Degrees	10	11	12	13	14	15
<6.99	0	0	1 3.2%	1 3.0%	1 3.6%	2 7.1%
7-10.99	2 6.3%	3 9.4%	1 3.2%	2 6.1%	3 10.7%	3 10.7%
11-14.99	5 15.6%	6 18.8%	10 32.3%	5 15.2%	9 32.1%	11 39.3%
15-18.99	14 43.8%	16 50.0%	17 54.8%	20 60.6%	13 46.4%	11 39.3%
19-22.99	10 31.3%	5 15.6%	2 6.5%	5 15.2%	2 7.1%	1 3.6%
>23	1 3.1%	2 6.3%	0	0	0	0
N=	32	32	31	33	28	28

NS-CP
Females

Degrees	10	11	12	13	14	15
<6.99	0	0	0	0	1 3.8%	3 13.6%
7-10.99	1 3.6%	2 6.9%	2 7.1%	2 7.7%	4 15.4%	3 13.6%
11-14.99	7 25.0%	9 31.0%	7 25.0%	7 26.9%	7 26.9%	4 18.2%
15-18.99	9 32.1%	9 31.0%	9 32.1%	11 42.3%	10 38.5%	9 40.9%
19-22.99	9 32.1%	9 31.0%	10 35.7%	6 23.1%	4 15.4%	3 13.6%
>23	2 7.1%	0	0	0	0	0
N=	28	29	28	25	26	22

Table F

One Year Growth Rotation
Males

Degrees	10-11	11-12	12-13	13-14	14-15
<1.0	19 59.4%	19 54.3%	20 58.8%	10 30.3%	9 32.1%
1.01-2.0	4 12.5%	9 25.7%	12 35.3%	10 30.3%	8 28.6%
2.01-3.0	5 15.6%	3 8.6%	2 5.9%	8 24.2%	7 25.0%
3.01-4.0	2 6.3%	3 8.6%	0	4 12.1%	2 7.1%
5.01-6.0	2 6.3%	1 2.9%	0	0	1 3.6%
>6.0	0	0	0	1 3.0%	1 3.6%
N=	32	35	34	33	28

One Year Growth Rotation
Females

Degrees	10-11	11-12	12-13	13-14	14-15
<1.0	19 67.9%	10 33.3%	12 38.7%	9 32.1%	12 54.5%
1.01-2.0	7 25.0%	11 36.7%	9 29.0%	13 46.4%	6 27.3%
2.01-3.0	2 7.1%	4 13.3%	7 22.6%	3 10.7%	3 13.6%
3.01-4.0	0	3 10.0%	1 3.2%	2 7.1%	1 4.5%
4.01-5.0	0	1 3.3%	1 3.2%	1 3.6%	0
>5.01	0	1 3.3%	1 3.2%	0	0
N=	28	30	31	28	22

One Year A-Pg(OP) Change

Males

Degrees	10-11	11-12	12-13	13-14	14-15
<-2.5	5 15.6%	5 14.3%	2 5.9%	3 9.1%	4 14.3%
-2.49- -1.0	7 21.9%	4 11.4%	5 14.7%	8 24.2%	7 25.0%
-.99- +1.0	15 46.9%	20 57.1%	18 52.9%	14 42.4%	8 28.6%
1.01-2.00	4 12.5%	4 11.4%	6 17.6%	3 9.1%	4 14.3%
2.01- 3.00	1 3.1%	1 2.9%	2 5.9%	4 12.1%	4 14.3%
3.01- 6.0	0	1 2.9%	1 2.9%	1 3.0%	1 3.6%
N=	32	35	34	33	28

One Year A-PG(OP) Change

Females

Degrees	10-11	11-12	12-13	13-14	14-15
< -2.5	1 3.7%	1 3.3%	0	0	1 4.5%
-2.49- -1.00	9 33.3%	5 16.7%	7 22.6%	2 7.1%	5 22.7%
-.99- +1.00	8 29.6%	21 70.0%	16 51.6%	17 60.7%	9 40.9%
1.01- 2.00	6 22.2%	2 6.7%	8 25.8%	5 17.9%	6 27.3%
2.01- 3.00	3 11.1%	1 3.3%	0	4 14.3%	1 4.5%
N=	27	30	31	28	22